Re-Wind: Architectural Design Studio and the Re-Purposing of Wind Turbine Blades

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Abstract

This paper discusses the opening moves of an international multidisciplinary research project involving researchers from Ireland, Northern Ireland and the US, aiming to address the global problem of end-of-life disposal of wind turbine blades. The problem is one of enormous scale on several levels: a typical 2.0 MW turbine has three 50m long blades containing around 20 tonnes of fibre reinforced plastic (FRP). It is estimated that by 2050, 39.8 million tonnes of material from the global wind industry will await disposal. Whilst land-fill is the current means of disposal, the nature of the materials used in the composite construction of wind blades (glass and carbon fibres, resins, foams) means it unsustainable. Hence, the project sets out to deploy innovative design and logistical concepts for reusing and recycling these blades. The project begins within an innovative joint design studio, staged between Queen's University Belfast and the Georgia Institute of Technology, where architecture students will, within the highly-constrained contexts of the blade properties and the potential reuse sites, systematically generate, filter, and prototype a selection of proposals, reusing the decommissioned wind turbine blades in buildings, infrastructure, landscape, and public art. The paper analyzes the potential and challenges of considering this highly constrained and yet multidisciplinary problem within the context of a Masters level Architecture studio. The paper concludes with an analysis of how outcome-driven design problems challenge traditional design studio cultures, acknowledging the need to make processes and ideas more explicit in order to categorise, analyse, rank and refine proposed architectural solutions.

Introduction

This paper discusses the opening moves of an international multidisciplinary research project involving researchers from Ireland, Northern Ireland and the US, aiming to address the global problem of end-of-life disposal of wind turbine blades. The overarching research problem is one of enormous scale on several levels: a typical 2.0 MW turbine has three 50m long blades containing around 20 tonnes of fibre-reinforced plastic (FRP). Wind blade designs for off-shore turbines are however expected to continue to increase in scale. The largest blade to date is 88.4 meters in length, (i.e 4 tennis courts long) and it is expected that this will become the norm as the demand for wind energy increases. With a life span of 20-25 years for each wind blade, this means that by 2050, approx. 40 million tonnes of material from the global wind industry will await disposal (Liu, P & Barlow, C.Y 2017; Bank et al 2018).

Currently wind blades at their end-of-life, can be recycled and/or disposed of in a range of ways. These include: the predominant strategy, landfill, where the whole resource goes to waste; various form of incineration: some of which may recover energy and/or some materials (defined as quaternary recycling (Bocken et al 2016)) chemical processing (defined as tertiary recycling) that recovers some materials but in a downgraded form; and finally, mechanical (mostly in the form of secondary recycling) which separates the resins from the fibres for use as filler reinforcement material i.e a downgrading process. All processes have negative implications: environmental, economic and/or as potential health hazards. The material nature of the blades' composite construction (glass and carbon fibres, resins, foams) means they are extremely difficult to 'deconstruct' in order to allow the materials to be reclaimed and reused.

Windblades are made primarily from glass fibre fabrics, with some carbon fibre in the high stress areas of longer blades. The fabrics are infused with a thermos-set resin, typically vinylester or epoxy. To provide high flexural stiffness with low weight, the skins and webs are typically produced as sandwich panels, with cores composed of balsa or foam (Figure 1). The balsa or foams are cut with a CNC router to conform to the airfoil shape, and the entire preformed package – fibre layers and cores – are placed in a single-sided mold and resin infused to form one massive monocoque structure. The resulting unitized structure is a significant advantage for manufacturing and promotes a long fatigue life for the blade, relative to other blade material systems. But of course the corollary of this unique and fiercely integral characteristic of windblades is that once constructed they are extremely difficult to deconstruct into constituent materials or smaller parts for 2nd / 3rd life purposes.

These end-of-life challenges have received very little attention to date (Ramirez et al 2016). Yet given how sensitive the general public have been around the resultant noise and ecological damage of wind turbines, there is a pressing need to develop sustainable end-of-life strategies that underpin rather than undermine wind-power's green credentials. Whilst policies may evolve over time to encourage manufacturers to develop circular strategies, research projects such as this lead the way within present contexts, deploying informed creativity to imagine future solutions.

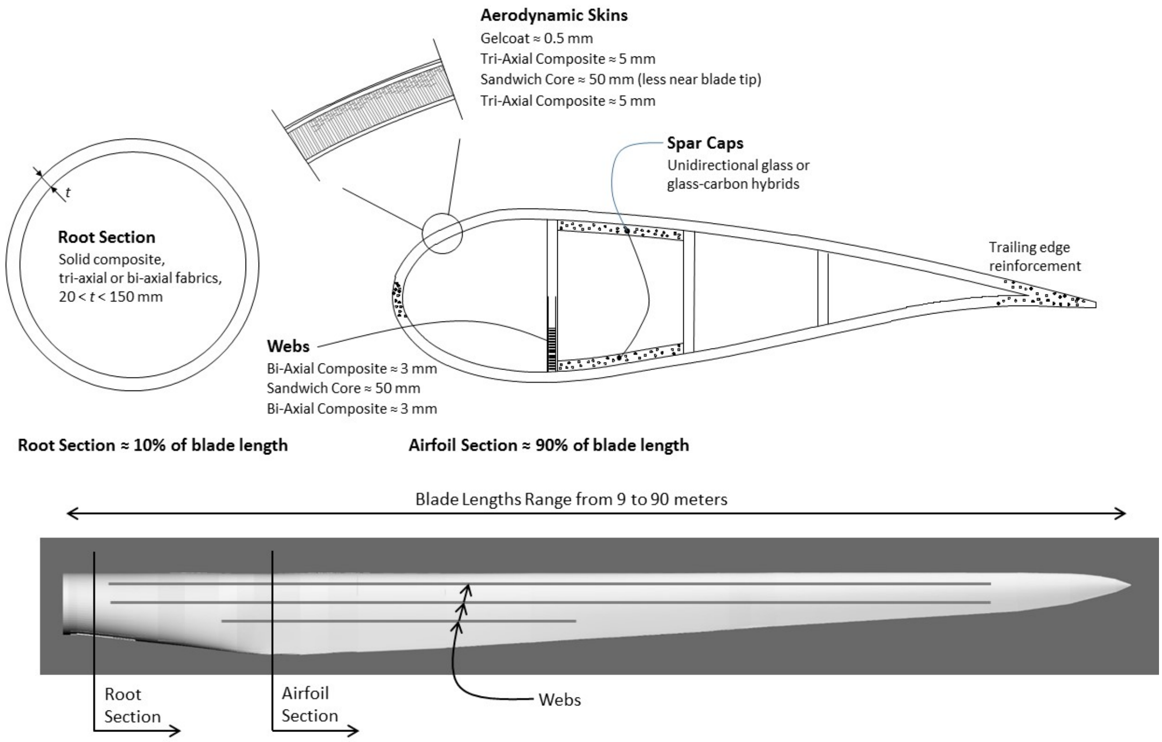

Figure 1: Typical blade construction (adapted from Gentry et al. (2018)).

The wider research project sets out therefore to deploy and marry innovative design and logistical concepts for reusing and recycling these blades. In other words: the project team understands decommissioned wind blades as being a significant, large scale and growing global resource of materials and components – conceptualised by the project team as ‘a New Forest’. The questions that then emerge are: what is the nature of the structure, materials, and components. How best might those materials be deployed in other applications? And can this done in ways that is environmentally cognisant of the contexts (social, cultural, economic) in which the wind-blades are currently located, and, of the potential new applications and location of markets for 2nd (and 3rd etc) life products?

Obviously the challenge is much greater than a three year project can fully address, but we have a diverse, international team of researchers and stakeholders, who understand that the process of generating, critiquing, prototyping and testing possible solutions will, in and of itself, provide a process template for future solutions for repurposing large-scale infrastructure materials and systems.

This paper focuses on the early stages of the research project where it is proposed to use masters level design studios in Schools of Architecture at both Queen’s University Belfast and Georgia Institute of Technology to generate and test initial ideas on how to repurpose wind blades. This is a rather unique beginning to what looks like an engineering problem. The paper will therefore discuss the value of bringing a design approach to the project. A fundamental research question for this paper is: How can a masters-level design studio bring value to this Research Project? To answer the question the paper will address: The Nature and Value of Design, especially in relation to Issues of Circular Economy; The significance of the students' role in such a research project; and the challenges to the normative format of Design Studio, when organized to be in direct support of a research project. We will then outline four strategies that have been identified and developed to respond to the challenges and hence deliver value to the research project; concluding with closing remarks on what this project might offer beyond a potential solution to the problem of repurposing wind-blades, and its significance.

The Nature and Value of Design

In his seminal book: *How Designers Think: The Design Process Demystified*, it takes Lawson to Chapter 3 to concede that he can find no one definition of design that is 'useful' – definitions are either so specific that they are quickly outdated or so generic that they are of little practical use. Instead he attempts to understand design by looking at how it is practiced over time and by whom. He charts the shift from craftsman as designer, where designing and making were synonymous and attuned to 'use', to the point where design professionals sit remotely both from the maker and the end-user. Cross (2001) also writes how researchers have tried to 'scientise' design, by trying to capture and pin it down to rationalized design methods, which ultimately were too inflexible and consequently ignored by practitioners. Contradicting Cross are design methodologies based on strict analytical protocols such as those described by Pahl and Beitz (1984), which are clearly appropriate in design of devices and systems where the relationship between part, assembly, and function can be clearly delineated. Recent thoughts on the role of designers align less to problem solving and more to *curating* complex 'messiness' into some semblance of structure - aware that with more time, more resources, a different team, in another context, the processes would vary and the design outcomes would differ.

Where research is engaged in analysis (sometimes implying deconstruction), design is concerned with anticipating and constructing new futures informed by knowledge of old patterns. It's this ability to future forecast and respond holistically to context and resources that makes design a natural bedfellow for sustainable circular practices – at least, potentially. Those involved in driving forward the Circular Economy have recognized this potential and the urgency in helping designers to develop more appropriate skills.

> *'Design will play a key role in the transition to a circular economy. We need to educate and inspire the design industry to take up this challenge*.'
>
> Sophie Thomas RSA REPORT 01 (2013)

A recent collaboration between the Ellen McCarthy Foundation (A UK based organization promoting an economy that is restorative and regenerative by design)

and IDEO (a global design firm) led to the production of a comprehensive online resource, 'The Circular Design Guide'. The Guide is targeted chiefly at product design and business however its tool kit and language provides a useful resource for and influence on this project.
The problem of using traditional design skills in a re-purposing project is described by Ali (2017) as one that requires both the understanding of *design process* as well as the *design of processes*, wherein the designer not only has empathy for the artifact but also for the logistics, workforce, and constraints imposed by the re-use problem. Ali cites the need for a decision support framework, to be developed and used by the designer as a means to judge the success of the re-purposed design proposal. Blizzard and Klotz (2012) provide a review of whole-systems design frameworks that are directly relevant to the development of a circular economy for wind turbine blades. According to Ali, in adapting architectural design problems to the circular economy, the focuses becomes more on means (processes) as opposed to goals (aspects of the designed artifact). This is necessary because of the material and geometric constraints applied by the product re-use scenario, which in the case of windblades, is evident.

Aside from the fact that designers can generate propositions for the re-use and repurposing of materials and components into second- and third-life products, designers also possess <u>strong 2-D and 3-D graphical skills</u>. These skills allow them to communicate holistic, complex ideas and strategies in ways that are remarkably accessible to a wider range of audiences, allowing a diverse research team to interact *through* images, models and prototypes rather than remain within linguistic and jargon-based silos.

The Design Studio

As stated earlier, the initial stages of the research project will be run through a Design Studio (Sept-Dec 2018). It's here that the research team's understanding of the problem will be presented and further evolved through design. The QUB students will generate as many ideas as possible and these will gradually be reduced in number over a semester by a process of testing, reflecting and critique, including the critique of design tutors, researchers and wider stakeholders. The outcomes will then be passed to Georgia Tech where they will be prototyped at part and full scale and further assessed through structural testing, and economic and life cycle analysis. The design studio is the perfect environment for this activity for a number of reasons:

Design Studios are peer- and interactive-learning environments that are framed around projects. Typically students are given project briefs set by Design tutors that mimic real life conditions. They respond to these projects over a few weeks, though at postgraduate level this is typically sustained over one semester. Students work alone and/or in teams but the intention of the designated studio space is to provide an environment where novice designers work and learn alongside one another. This occurs through a continuous process of informal feedback on their investigations and propositions, supplemented on a weekly basis with more formative feedback and critique from design tutors and invited experts.

The Design studio is regarded as a safe space where students are encouraged to test the edges of a problem. Experimentation is not only permitted but also expected – since by pushing at the edges of an idea students are simultaneously learning and testing their own skills, knowledge and values.

The process in the Design Studio is a rigorous one where students are encouraged to work iteratively and to move through and test ideas across a range of scales. Circular design draws heavily on this skill of moving between scales, but it also challenges us to not only consider physical scale i.e. product, buildings, landscape, infrastructure, but also to consider the systems they sit within i.e. manufacturing, economic and social (EMF and IDEO, 2017).

Aside from setting the pedagogical framework for the design studio, the Design Tutors are there to encourage students to experiment with a range of tools, tactics and methods to enrich and develop their own praxis. In addition their role is to help students to either converge their thinking to deliver outputs within given timescales, or indeed to open up their thinking to further explore alterative possibilities. The same brief will draw as many different design outcomes as there are students – no one answer is 'right' , though some are 'better'. However the aim of design studio teaching is ultimately to ensure that the students develop their own voice and most especially, a strong critical engagement in their own work, since this is the fundamental driver for their future design practice: '*Our role is not to help people towards our understanding of architectural practice, rather, their own'* (Morrow 2015).

So the design studio, when properly structured, is a place where high levels of creativity are mixed with rigorous critique; where multiple voices are supported and yet where delivery of tangible outcomes is assured. To paraphrase Masschelein, an educational philosopher, the design studio is a unique space that creates a gap between what is possible and what is actual (Masschelein 2011).

The Students' Role

Placing the initial design idea generation phase within a postgraduate design studio allows us to capitalise on the creative capacity of architecture students. We intend to assign this research problem to around 15 students over an 11 week period. The studio provides a design resource that we would not be able to afford by other means, but the challenge is to ensure that not only does it deliver products to our research project but also that the learning experience of the students is a full and positive one. To that end, we draw on the team's established experience of running live projects as part of the design curriculum (Morrow & Brown 2012).

> *"A live project comprises the negotiation of a brief, timescale, budget and product between an educational organisation and an external collaborator for their mutual benefit. The project must be structured to ensure that students gain learning that is relevant to their educational development."*
> Anderson and Priest, 2016

The students' role is also much more fundamental, on two levels. Firstly the project is better served by having as varied a range of ideas at the outset as possible; and as previously described: the design studio and the tutors are purposefully there to support diversity of outcomes. A professional design office would be more likely to converge on a narrower bandwidth of ideas that map to their expertise and profile. Secondly, by involving students we follow one of the areas of recommendations set out in the RSA's 2013 Report on design in the circular economy, which is to skill up the Design Industry, preparing future generations of designers by integrating design for circular economy and systems thinking into the design curricula and creating moments of cross-curricular learning, connecting designers with engineers, material scientists, etc.

Design Studio Challenges

In advance of the design studio running we are mindful that there are conventions within Architecture Design Studio Culture that might offer some resistance to the project. The four key areas are mapped out below.

1. Scope and Scale. Architecture Design Studios can focus on a range of scales – from large to small: urban design, landscape, buildings or furnishings. Rarely however do studios occur where all scales are considered at the same time, simply because it's difficult to manage and can be confusing for the students involved. However when designing for a circular economy, and especially for the massive wind blades we are focused on, the designer must be aware of all scales and their associated systems. This means that students in this studio must be able to understand their propositions from the large, geopolitical context to the small, the nature of the constituent materials of wind blades.

2. Product over Process. Architecture design studios rely heavily on tutors drawn from practice so there is a cultural tendency for student work to be judged more on the architectural, rather than the learning outcomes; and when that is the case it is the final design product that predominates. Given the scale of this project and the relative early stage thinking around circular design processes, it is unlikely that we will have strong design outcomes after 11 weeks. However the research team recognises that the process of generating, critiquing, prototyping and testing possible solutions will, in and of itself, provide a process template for future work in this area. This presents yet another challenge for the project since because of the dominance of the 'artefact' in design studio culture, design processes (which include the decision making) often lie hidden. These however are critical to a research project that by its nature must reveal its ‘raw data’ for examination by later researchers. The challenge here is to capture and make explicit the process.

3. Proposal to Prototype. The proposals developed by QUB students will become inputs to a detailing and prototyping workshop, to be held at Georgia Tech in Atlanta in Fall 2019. The intent is that the handoff between designers and detailers/prototypers leads to a close relationship between ideas and realisations. The obvious difficulty here is that the prototyping students may wish to re-engage in a design process – from the start – rather than to move forward with assessment, re-design as necessary, detailing, and prototyping. Two strategies have been developed to aid in the integration of the two phases: first, both sets of students will complete a sandwich panel composites making workshops – using the same materials and techniques, to build competence and community between the two groups. In addition, the QUB student will be visiting Georgia Tech in Spring 2018 to present their proposals to the prototyping workshop and further build community.

4. Other Voices. Design Studios aim to support diversity but in reality students are rarely exposed to any views or expertise beyond architecture. This generates a value system that is implicit and thus difficult to challenge. It could be argued that without this discourse at the ‘coal-face’ of design education, students are unprepared for the challenges that lie ahead.

Addressing Pedagogical Issues in the Re-Wind Project

This section outlines the means by which we will address the challenges outlined above.

Scope and Scale: We will develop, in agreement with the research team a clear <u>Visual-based Narrative</u> that explains the need and challenges of recycling blades as they are known at the project’s outset. A Masters of Architecture Student has been appointed to carry out this work in advance of the Design studio in order that we can use it to engage and attract students into the design studio. It’s anticipated that the research team will also use it to promote the project to wider stakeholders. The clarity of this visual narrative is critical in ensuring that we are all moving in the same direction, yet also allows for creative freedom. As the studio begins we will also begin to <u>Create a Precedent Map</u>. Traditionally Design students look to built precedents for influence, however it is sometimes a shallow gesture and quickly forgotten. Our approach will be to treat this with more rigor, extending the process to collate as many precedents as possible, including process precedents. that are relevant to the project. They will be analysed, categorised and mapped so that we can also spot and understand what is missing from the map. This helps us to build off the expertise and endeavours of others yet also identify potential new areas of investigation.

Product over Process: Documenting the decision making process is critical so we will use two devices. The first is known as <u>Spread Sheet Critique –</u> this involves a formalised and documented process that records each design proposition (visually and textually); analyses the propositions from a range of perspectives; identifies and lists the next possible steps in development; associated risks, and any outstanding questions. This document will be critical in allowing others within and beyond the project to critically retrace or challenge the process.

Proposal to Prototype: Material understanding is a fundamental component of the Circular Economy. It is critical that designers go beyond the graphical image of a proposal and understand its material nature (embodied energy, workability, life span etc) and impact (environmental, health). In order to bring the students to this level of understanding we intend to trial two techniques. The first is known as a 'Teardown'. This refers to a reverse engineering process, used within the RSA's Circular Economy Design workshop, which offered participants the opportunity to take apart an existing product in order to understand its material complexity. In this instance we intend to deconstruct a small section of a blade. The second technique is a Kit Build where we will design a workshop allowing students to work directly with composite materials, making their own element. The aim is to embed a physical, intimate and tacit material knowledge of composite construction that students can draw on when designing larger scale propositions for wind blades.

Other Voices: For this we will open up the studio to Expert Voices from outside architecture. These formative moments will occur throughout the semester and will allow us to critique the propositions as they are being evolved by the students, from a series of technical, environmental and social perspectives. The Re-Wind project is staffed by a large group of experts with backgrounds in wind power, life cycle assessment, geographic information systems, composite materials, structural engineering, community based practice etc. The role of these experts will be acknowledged and harnessed in the design studio, without overwhelming the students or over-constraining the design process. The integration of experts and their knowledge into the project is described in the next section. (see also fig 2).

Project Structure

The design effort for the overall project is structured into four major phases: (1) a preparation phase, where data and tools are assembled and organized for the design studio; (2) the design studio at QUB which is the focus of this paper; (3) the prototyping workshop at Georgia Tech and (4) the design documentation phase at the end of the two courses.

The QUB studio is also structured in four phases as described below (Figure 2).

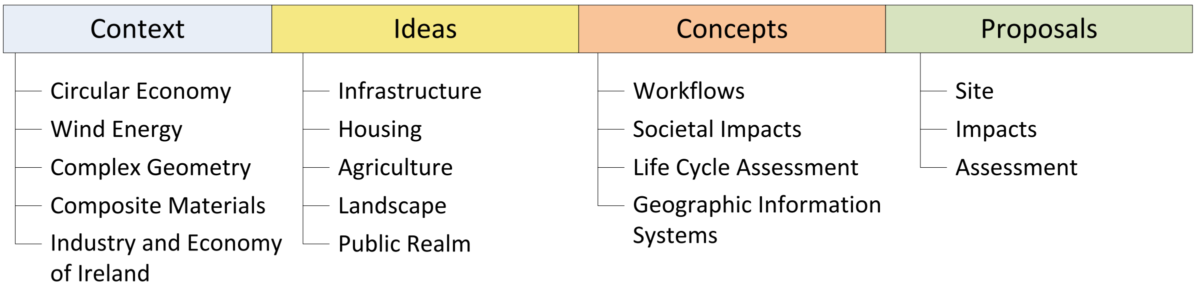

Figure 2: Structure of the Windblade Re-Wind Design Studio at QUB.

1. **Context.** In the first phase of the course, the students are introduced to background knowledge from a wide range of experts – all of whom are members of the Re-Wind research team. In this way, the student designers are equipped to apply this knowledge and "model the experts" in the design process, as described by Christiaans and Venselaar (2005). The problem is uniquely suited to the Island of Ireland, due to: the large installed base of wind power on the island, the environmental ethic of the governments and people of the island, the focus on economic development and preservation of Irish resources.

2. **Ideas.** The second phase of the studio focuses on ideation, that is, the generation of a large number of design propositions in wide range of domains. These ideas will be developed through sketching, coarse 3D modeling, and through discussions with experts, stakeholders, and potential clients for the second-life windblade products. It is anticipated that each student will develop 5 to 10 ideas. At this stage of the design process, the merit of ideas are not assessed – none are too outlandish nor too pedestrian to be considered. The class will develop a pattern book of ideas – and the ideas of other Re-Wind team members (engineers, physical scientists, social scientists) will be interleaved with those generated by the students.

3. **Concepts.** The third phase of the course include the development of workflows (ie design of processes per Ali (2017)) and the formulation of assessment strategies to quickly assess the ideas generated in phase 2. Promising ideas will be identified and alloyed with informal workflows that depict the windblades as they transition from tower through remanufacturing to re-use site. Assessment will include metrics that assess the percentage of material reused, the carbon sequestration by mass and duration, and the potential societal impacts (both positive and negative) of the idea. We anticipate that each student will generate three concepts, each taken from either one of their own ideas – or from the ideas of other students or project team members.

4. **Proposals**. Finally, each student will develop one proposal that embodies the traditional deliverables for an architectural project, including the selection of specific windblades from the Island of Ireland, at a specific site. The re-use application will be fully documented at a specific (likely different) site, and with fully documented architectural and process drawings. The proposals will include a refined process model documenting the geographical and logistical operations necessary to transform the windblades from active use on a tower to the re-

purpose application on the Island of Ireland. The proposals should have sufficient detail for the follow-on prototyping workshop at Georgia Tech as well as for the team of ecological and social scientists and structural engineers whose work will follow the design studio.

Significance and Conclusion

This Paper was written as we were planning the Design studio (6months in advance) so it has helped to frame and provide a wider context and place for reflection on the nature of the challenge than would normally be the case. This means that there are, at the point of writing, no research 'findings' for the paper to report. However as we plan how best to conjoin a Design studio and a research project we have started to consider that there is potential for the project to trigger other outcomes beyond those outputs we initially anticipated. We believe that the visual 2 and 3-D outputs of the design studio can be used to raise greater public awareness around windblades and circular economy issues and as such we hope to curate a series of public exhibitions/ presentations. The design process and project as a whole will identify those aspects of current blade design and material composition that present the greatest difficulty when repurposing, and we hope that information may potentially influence the design of future blades. We also understand that whilst the scale of the problem addressed by the research project is vast – any solutions will create commercial opportunities of a relative scale and significance. This will be a new area of industry that needs a new generation of professionals. So finally, by aligning a research project to a design studio we believe it has the potential not only to demonstrate the power of design thinking in these complex, large scale situations but will offer a new form of design studio from which a generation of 'circularity' designers with emerge.

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